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Dynamics of nitrogen in some soils and potted maize plants amended with sources of nitrogen fertilizers

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Abstract

In this study, the effects of urea, poultry manure, and slow-release nitrogen fertilizers on the release of nitrogen from certain soils were examined. Two soils from different locations (Shao and Malete) were subjected to nitrogen sources (prilled urea, granular urea, neem-coated urea, and poultry manure) at a rate of 120 kgN/ha during the incubation experiment, while the control group received no nitrogen at all. After incubation for 0, 2, 4, 6, and 8 weeks, soil samples were collected. To ascertain the NO_3-N and $NH4^+$-N, soil samples taken from the pots were examined. Similarly, a screen-house was used for two cycle experiments in which the maize plants were cultivated in pots with the same treatments set up in a completely randomized design. The incubation investigation demonstrated that whilst neem-coated urea had a little impact on nitrogen availability, the addition of granular urea and poultry dung increased nitrogen availability. The maize plants grew well in all treatments, demonstrating that the various nitrogen sources had no negative effects on plant growth. However, as compared to the plants grown with prilled urea and neem coated urea at first and residual harvest, the plants grown with urea and poultry manure had significantly growth and higher dry matter yield. The findings indicated that growing maize in soil amended with poultry manure can be a safe way to add more nitrogen while reducing the possibility of excess nitrogen leaching into the environment and can serve as a substitute for mineral fertilizer.

1 Introduction

A significant contribution to agricultural productivity has come from fertilizers in general and nitrogenous fertilizers in particular. To increase crop output and reduce fertilizer-related environmental issues, nitrogenous fertilizer efficiency must be continuously improved. One of the most crucial and limiting minerals for agricultural crop production systems is nitrogen (N). (Motasim et al., 2024). To increase crop yields and satisfy the rising demand for food, chemical fertilizers have been overused in recent decades (Bisht and Chauhan, 2020).

Around the world, urea is a major synthetic fertilizer that is used as the primary source of plant nutrition (Tong et al,. 2018). Despite raising the amount of nitrogen (N), traditional urea is ineffective since plants only absorb and use a portion of it (Swify et al., 2024). According to Olowoake et al. 2022, prilled urea is a nitrogenous fertilizer that releases rapidly and is often spread in splits, causing major losses like surface runoff, ammonia volatilization, immobilization, and denitrification. These losses are detrimental to the environment and have resulted in a number of agroecological problems. In dry-land rabi crops, however, deep application of slow-release nitrogenous fertilizers, like granular urea, reduces loss and increases use efficiency (Olowoake et al., 2022). According to Motasim et al. (2021), the usage of granular urea fertilizer is concerning because of its high nitrogen loss and low nitrogen utilization efficiency (NUE), which varies between 10 and 50%. Without adequate fertilizer management, plants are unable to absorb more than 50% of the nitrogen from urea. The largest percentage of urea loss (64%) was observed when it was broadcast on the field (Motasim et al., 2024). Water pollution, eutrophication, acid rain, ammonia volatilization loss, nitrous oxide emission, global warming, and stratospheric ozone

depletion are some of the possible environmental degradations that may result from it (Sutton et al., 2022; Puga et al., 2020). Large concentrations of N, P, and K are found in poultry manure, along with secondary and trace elements like B, Ca, Cu, Fe, Mg, Mn, S, and Zn. Poultry manure, when properly applied, can enhance soil and plant health and productivity by supplying vital nutrients that promote plant growth (Agbede, 2025). Poultry manure has been found in a number of studies to enhance CO_2, NH_3, and N_2O gas emissions when added to soils (Jekins *et al.*, 2025; Anderson et al., 2021). Through microbial ammonification and nitrification, manure contributes organic N and organic C, promoting the mineralization of organic N and C and producing NH_4 + and NO_3 as well as N_2O through denitrification (Syamsiyah *et al.*, 2023). In the past, farmlands have used poultry manure to improve soil fertility based on crop N requirements.

In order to decrease gaseous and leaching losses of nitrogen from intensively managed agricultural systems, significant research efforts have also been directed towards creating appropriate mitigation techniques (Hassan *et al.*, 2022; Mahmud et al., 2021:). The use of enhanced efficiency or controlled release fertilizers to reduce nitrogen loss and increase crop usage efficiency are examples of mitigation measures that have been the subject of much research in recent decades (Carstensen et al., 2020; Govil et al., 2024). Neem coated urea (NCU) fertilizer is becoming a more popular alternative to granular urea for production since it performs better in terms of crop output and N uptake (Rehman et al., 2021; Ali et al., 2020). The mineralization of slow-release N fertilizers applied to Nigerian soils and potted maize plants is either poorly understood or nonexistent.

Therefore the present investigation was, made to compare the N dynamics of granular urea, prilled urea, poultry manure and neem coated urea in some soil under incubation (laboratory) and potted maize plant under screen-house condition.

2 Materials and methods

2.1 Soil collection and analysis

The soils were collected at a depth of 0 to 15 cm from the Kwara State University Teaching and Research Farm in Malete and the Kwara ADP farm in Shao, Ilorin, Nigeria, which is located in the southern Guinea savanna zone of Nigeria. They were then air-dried and sieved using a 2 mm screen. The following physical and chemical characteristics were identified in the lab. The soils' subsamples were gathered and examined for the following characteristics: Using a glass electrode pH meter, the pH of the soil was calculated in a 1:2 ratio (soil: water). Bouyoucos, (1962) used the hydrometer method to determine the particle size. We used the Kjeldahl method to evaluate total nitrogen. According to Baker, (1976) colorimetric analysis was used to determine organic carbon. Exchangeable cations were extracted using 1 N ammonium acetate; atomic absorption spectrophotometers were used to determine the presence of Ca and Mg in the extract, while flame photometry was used to determine the presence of Na and K. Cataldo et al. (1975) utilized a UV-3200 PCS spectrophotometer to detect the levels of ammonium and nitrate nitrogen. Available micronutrients (Fe, Mn, Zn, and Cu) were extracted with 0.1N HCl, and

determined by the use of Atomic Absorption Spectrophotometer. Particle size analysis was determined by the hydrometer method of Bouyoucous (1951) using calgon as a dispersing agent as described Mwendwa, (2022).

2.2 Experimental design

The screen-house and incubation tests were set up using a completely randomized design. Five treatments—prilled urea, granular urea, neem-coated urea, well decomposed poultry manure, and no amendment (control)—were used in the three replications of the trials.

2.3 Laboratory incubation

After being filtered using a 2 mm sieve, the soils (gathered from the two sites, (Malete and Shao) weighing 300 g each were poured and filled into plastic containers and securely sealed. Separate applications of control, 120 kgN/ha of poultry manure (0.8 g), prilled urea, granular urea, and neem coated urea were made into each plastic and combined. After being maintained in a dark cabinet for eight weeks, the soil and amendment mixture was watered to field capacity. The treatments were set up in three replicates using a completely randomized design (CRD). Distilled water was occasionally added to the moisture content to bring it up to field capacity.

Every day, a thermometer was used to measure the incubation cupboard's temperature. At 0, 2, 4, 6, and 8 weeks of incubation, soil samples were collected, and their ammonium and nitrate nitrogen contents were examined. Table 1 provides information on the chemical composition of the poultry manure utilized in the investigation.

Table 1
Chemical composition of poultry manure

	Nutrient				
	pH	EC (dS/m)	N (%)	P (%)	K (%)
Poultry manure	7.8	5.60	2.28	0.54	2.05

2.4 Screen-house experiment

In a screen-house, this was a two-cycle experiment. Plastic pots with a capacity of 8.2 kg of soil (approximately 25–30 cm diameter and 25–30 cm depth) were used. Each pot was filled with air-dried, sieved soil from the respective locations (Kwara State University in Malete and Kwara ADP farm Shao). Five treatments; prilled urea, granular urea, poultry manure, neem-coated urea at 120 kgN/ha, and no amendment (control) were used in the three replications of the trials. The poultry manure applied in this study was well-decomposed prior to use. Three maize seedlings per pot were planted after the soil samples in the pots. Pots were watered to maintain soil moisture at approximately 60–70% of field capacity throughout the experiment. Moisture was monitored regularly (every 2–3 days) by weighing the pots and replenishing the lost water. Care was taken to avoid both waterlogging and excessive drying,

ensuring uniform moisture conditions across treatments. After two weeks, the number of plants per pot was reduced to one. The plants were observed in the screen-house for eight weeks and watered as needed.

Samples of soil were also collected at 0, 2, 4, 6, and 8 weeks following planting. Samples of soil were taken from the pots by using a spoon to gather samples around the plant root at a depth of 0 to 15 cm. The samples were then bulked to provide a representative sample from each pot. Nitrogen levels in ammonium and nitrate were measured in soil samples that were collected. Soil samples were gathered at 0, 2, 4, 6, and 8 weeks following planting, and same procedure was repeated in the second maize cycle.

2.4 Agronomic Data Collection

Data on the growth and yield characteristics of maize plants, including stem girth, number of leaves, leaf area, plant height, and dry matter yield, were collected every two weeks.

2.6 Statistical Analysis

A statistical analysis of variance was performed on the obtained data, and Duncan's Multiple Range Test (DMRT) was used to assess significant differences between the treatment means at a 5% probability level.

3. Results

3.1 Physico-chemical properties of the soil

Table 2 displays the soil's physicochemical characteristics prior to planting. Shao and Malete textural soil is loamy sand, neutral, and has low levels of available phosphorus and total nitrogen, according to the data.

Table 2
Physico-chemical properties of experimental site (Malete and Shao)

Parameters	_____ Soil test value_____	
	Malete	Shao
pH(H_2O)	7.19	6.65
Org.C(%)	2.40	2.13
Total N (%)	0.26	0.20
P (mg/kg)	3.10	4.00
Exchangeable bases (cmol/kg)		
Mg	1.04	0.91
Ca	3.16	2.83
Na	0.91	0.96
K	0.62	0.16
Extractable micronutrients (mg/kg)		
Cu	1.13	1.27
Fe	91.0	103.0
Mn	83.0	96.0
Zn	1.21	1.40
Sand (%)	80.3	82.0
Silt (%)	11.7	12.0
Clay (%)	8.0	6.0
Textural class	Loamy sand	Loamy sand

3.2 Dynamics of soil nitrate nitrogen

Table 3a demonstrates that the amount of nitrate nitrogen released in Shao soil varied significantly throughout the course of the weeks when various fertilizers were applied. In the Shao control soil, NO_3-N increase from two weeks after incubation (2 WAI) to 6 WAI and then decreased at 8 WAI, however there was a decrease at 2 WAI compared to 0 WAI. Granular urea application raised NO_3-N at 2 WAI, whereas increases were seen at 4, 6, and 8 WAI, with the most significant increase occurring at 8 WAI. At 8 WAI, neem-coated urea raised NO_3-N from 0 WAI throughout the course of the weeks. At 0 WAI, poultry manure generated the most NO_3-N, which decreased at 2 WAI and then increased again up to 8 WAI.

NO_3-N at 0 WAI rose from 2 WAI to 8 WAI for Prilled Urea. Throughout the weeks, the NO_3-N values of the soil obtained from Malete are displayed in Table 3b. The NO_3-N released in the control soil indicates a drop from 0 WAI to 2 WAI. Up until 6 WAI, NO_3-N rose as the weeks went by, and then it started to decline at 8 WAI. NO_3-N for granular urea rose from 0 WAI and continued to rise over the next few weeks, reaching 8 WAI.

The use of urea coated with neem caused NO_3-N to rise to 8 WAI. At 2 WAI, NO_3-N for poultry manure started to decline, but it rose as the weeks went by, reaching its maximum at 8 WAI. The amount of NO_3-N released over the course of the weeks increased significantly with the addition of prilled urea.

Table 3
a: NO_3--N concentration (%) in Shao soils treated with different fertilizers during the eight weeks of incubation

Treatment	0 wks	2 wks	4 wks	6 wks	8 weeks
Control	0.05b	0.01b	0.1a	1.25a	0.94d
Granular urea	0.02c	0.02ab	0.16b	1.05c	1.41a
Neem coated urea	0.02c	0.03a	0.47a	0.94e	1.02c
Poultry manure	0.29a	0.03a	0.5a	1.14b	1.24b
Prilled urea	0.01c	0.02ab	0.42a	1.02d	1.03c

Means having the same letter along the columns indicate no significant difference using Duncan's Multiple range test at 5% probability level

Table 3
b: NO_3--N concentration (%) in Malete soils treated with different fertilizers during the eight weeks of incubation

Treatment	0 wks	2 wks	4 wks	6 wks	8 weeks
Control	0.23b	0.01c	0.12c	0.98c	0.92d
Granular urea	0.01cd	0.15a	0.4b	1.12b	1.18b
Neem coated urea	0.01cd	0.02bc	0.5ab	1.26a	1.29b
Poultry manure	0.44c	0.16a	0.43b	1.2ab	1.36a
Prilled urea	0.02c	0.03b	0.61a	0.99c	1.03c

Means having the same letter along the columns indicate no significant difference using Duncan's multiple range test at 5% probability level

3.3 Dynamics of soil ammonium nitrogen

Table 4a displays the ammonium content values of soil taken from Shao over several weeks that was treated with various fertilizers. As the number of weeks increased, the concentration of ammonium nitrogen in the soil altered, and the patterns of release for control, granular urea, neem-coated urea, poultry manure, and prilled urea all showed distinct patterns. The soil from Shao had the greatest $NH4^+$-N levels at 0 WAI for control. The $NH4^+$-N level dropped at 2 WAI and then rose over the control weeks.

The value of $NH4^+$-N at 0 WAI was comparable at 2 WAI and then grew significantly at 4 WAI. From then, it increased sharply over the next few weeks, reaching its most significant rise at 8 WAI for granular urea treatment. The amount of $NH4^+$-N released by neem-coated urea was considerably lower at 0 and 2 WAI and then increased as the number of weeks increased. $NH4^+$-N was higher in soils supplemented with poultry manure at 0 WAI, dropped at 2 WAI, and then rose during the next 8 WAI. Granular urea and pelleted urea had comparable responses. At 4 WAI, prilled urea raised $NH4^+$-N for the remaining weeks; this pattern persisted at 6 and 8 WAI.

Malete soil ammonium levels over the course of several weeks are displayed in Table 4b. The $NH4^+$-N values released at 0WAI for the control group dramatically decreased at 2 WAI and rose from 4 WAI over the next few weeks, but the drop was minimal at 8 WAI. Lower $NH4^+$-N was released by granular urea at 0 WAI, and this amount increased as the weeks went by, reaching 6 WAI and then a substantially lower level at 8 WAI. For neem-coated urea, the $NH4^+$-N value at 0 WAI was comparable at 2 WAI and then increased sharply at 4 WAI. From there, it grew over the next few weeks, reaching its most significant rise at 8 WAI.

The most NH4+-N was produced at 0 WAI by adding poultry manure, and it significantly ($P < 0.05$) decreased in the weeks that followed. From 4 WAI, $NH4^+$-N rose dramatically to 6 WAI, and then it decreased at 8 WAI. Lower $NH4^+$-N was released by prilled urea at 0 and 2 WAI, but $NH4^+$-N was noticeably higher at 4 WAI. $NH4^+$-N abruptly rose during the remaining weeks.

Table 4

a: $NH4^+$-N concentration (%) in Shao soils treated with different fertilizers during the eight weeks of incubation

Treatment	0 wks	2 wks	4 wks	6 wks	8 weeks
Control	0.3a	0.0c	0.01e	0.52d	0.52d
Granular urea	0.01c	0.01b	0.09d	0.68a	0.78a
Neem coated urea	0.01c	0.0c	0.26b	0.58c	0.57c
Poultry manure	0.16b	0.02a	0.28a	0.64b	0.69b
Prilled urea	0.01c	0.01b	0.24c	0.57c	0.57c

Means having the same letter along the columns indicate no significant difference using Duncan's Multiple range test at 5% probability level

Table 4

b: $NH4^{+}$-N concentration (%) in Malete soils treated with different fertilizers during the eight weeks of incubation

Treatment	0 wks	2 wks	4 wks	6 wks	8 weeks
Control	0.13b	0.01b	0.06e	0.52b	0.51e
Granular urea	0.01c	0.08a	0.22d	0.62ab	0.56d
Neem coated urea	0.01c	0.01b	0.28b	0.7a	0.76a
Poultry manure	0.24a	0.09a	0.24c	0.7a	0.66b
Prilled urea	0.01c	0.02b	0.34a	0.55b	0.58c

Means having the same letter along the columns indicate no significant difference using Duncan's Multiple range test at 5% probability level

3.4 Growth parameters as affected by minerals and organic Fertilizers during first and second planting on Shao and Malete soil

The response of maize plant height to fertilizer treatments applied at Malete and Shao during the first and second plantings is displayed in Table 5. During the initial planting in Malete, it was found that poultry manure produced the highest plant height at 4, 6, and 8 weeks after planting (WAP), which was significantly ($P < 0.05$) different from all other treatments. With the exception of 8 WAP, where granular urea had the largest significant plant height, the similar pattern was also seen at Shao at 4 and 6 WAP. Among the fertilizer treatments, maize plant height varied considerably ($P < 0.05$) at residual planting in every week following planting. At 4, 6, and 8 WAP at Malete and Shao, respectively, the application of poultry manure resulted in a significant ($P < 0.05$) increase in the height of the maize plants.

Table 5
The effects of poultry manure, urea and neem coated urea on maize plant height (cm) at different sampling periods during first and residual planting on Malete and Shao soil

Treatment	Malete			Shao		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
	cm			cm		
First planting						
Control	20.9b	26.4c	41.3e	15.5c	25.5d	38.3e
Prilled urea	24.8a	31.0 b	44.5d	24.5a	35.0b	50.7d
NCU	27.5a	30.0b	60.8c	20.0a	33.0c	61.0c
Granular urea	27.5a	35.0a	85.2b	23.0a	35.0b	87.2a
Poultry manure	26.3a	35.0a	93.4a	24.3a	45.0a	78.1b
Residual planting						
Control	8.8b	26.7c	32.8c	8.2b	23.3b	37.3c
Prilled urea	11.0a	37.7b	52.1b	12.7a	33.3a	41.2b
Neem coated urea	10.5a	36.3b	54.7b	12.3a	33.3a	42.1b
Granular urea	10.3a	35.3b	55.4b	11.0a	31.3a	45.4b
Poultry manure	11.3a	44.2a	79.6a	11.3a	33.0a	57.2a

Means having the same letter along the columns indicate no significant difference using Duncan's Multiple range test at 5% probability level

Table 6 displays how many leaves responded to fertilizer treatments applied at Malete and Shao during the screen house's initial and second plantings. Poultry manure had the most leaves at 4, 6, and 8 WAP, which was not much different from granular urea at the same WAPs in Malete. Granular urea had the most leaves at 6 and 8 WAP in Shao soil, but the values did not differ substantially from those of poultry manure at the same time.

Furthermore, at residual planting poultry manure was significantly higher ($P < 0.05$) when compared with the other fertilizer treatments at 4, 6, and 8 WAP in Malete and Shao soil respectively.

Table 6
The effects of poultry manure, urea and neem coated urea on maize number of leaves at different sampling periods during first and residual planting on Malete and Shao soil

Treatment	Malete			Shao		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
First planting						
Control	5.1b	7.0b	9.1c	5.0 c	6.2d	9.0c
Prilled urea	6.3a	10.0a	11.7b	6.2 b	7.3c	11.0b
NCU	6.5a	11.0a	11.6b	6.4b	9.4b	11.0b
Granular urea	7.0a	11.2a	12.0a	6.0b	11.3a	13.8a
Poultry manure	7.3a	12.0a	13.3a	9.0 a	11.2a	12.5a
Residual planting						
Control	4.0a	6.1c	8.7c	5.0b	7.0b	9.9c
Prilled urea	6.0a	9.0b	10.7b	7.7a	10.7b	11.0b
Neem coated urea	6.4a	9.2b	11.0b	7.3a	10.0b	11.3b
Granular urea	6.5a	10.0a	11.5b	7.3a	10.0b	11.7b
Poultry manure	6.7a	11.3a	12.3a	7.7a	12.0a	12.8a

Means having the same letter along the columns indicate no significant difference using Duncan's Multiple range test at 5% probability level

The response of stem girth to fertilizer treatments applied during the first and second plantings on Malete and Shao Soil in the screenhouse is displayed in Table 7. At 4, 6, and 8 WAP, the stem girth varied significantly. Poultry manure was shown to have the largest significant ($p < 0.05$) stem girth in Malete soil at 4, 6, and 8 WAP. Throughout the growing season, there was no discernible difference in the stem girth values from poultry manure and granular urea. The poultry manure treatment resulted in greater stem girth than the other treatments in Shao soil at 4 WAP during the initial planting. However, for stem girth made from NCU, granular urea, and poultry manure, no significant ($p < 0.05$) differences were found at 6 and 8 WAP. In both soils, the control treatment yielded the smallest stem girth at various sample times. The stem girth values of the maize plants during the residual planting indicate that the fertilizer treatments given to the potted soil from Malete and Shao, respectively, did not significantly differ from one another. The shortest maize stem girth was consistently produced by the control treatment.

Table 7
The effects of poultry manure, urea and neem coated urea on maize stem girth (mm) at different sampling periods during first and residual planting on Malete and Shao soil

Treatment	Malete			Shao		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
	———mm ———			——— mm ———		
First planting						
Control	6.00a	6.19b	7.60c	7.89c	8.94b	9.07b
Prilled urea	6.24a	7.79a	9.30b	9.37b	13.48a	13.60a
Neem coated urea	6.24a	7.79a	9.71b	10.51a	13.47a	13.68a
Granular urea	5.23a	8.02a	10.03a	10.46a	13.75a	14.52a
Poultry manure	6.58a	8.62a	11.32a	10.98a	13.43a	14.00a
Residual planting						
Control	3.56b	5.93b	8.80b	2.19b	4.35b	9.02b
Prilled urea	4.86	7.12	10.31	4.60	7.19	10.37
Neem coated urea	4.63	7.06	10.46	4.85	7.44	10.02
Granular urea	5.25	7.70	10.61	4.64	7.70	11.21
Poultry manure	4.96ns	7.98ns	11.81ns	4.70ns	7.75ns	12.22ns

Means having the same letter along the columns indicate no significant difference using Duncan's Multiple range test at 5% probability level

3.5 Fresh and dry matter weight of maize as affected by fertilizer treatments

Different fertilizers' impacts on fresh and dry matter yield at initial and residual planting from potted soil in Malete and Shao are shown in Figs. 1a and 1b. Significant differences ($P < 0.05$) were seen between all treatments and the control. There were significant ($P < 0.05$) differences between the fertilizer treatments in the fresh shoot weight and dry matter weight of the maize plants during the first planting. Applying poultry manure to potted soil in Malete and Shao resulted in a significantly increased fresh and dry shoot weight, followed by granular urea. The fresh and dry shoot weight that was produced was the least by the control treatment.

The fertilizer treatments had a significant ($P < 0.05$) impact on both fresh and dried shoot weight at residual planting (Fig. 1b). From Malete and Shao potted soil, poultry manure yielded the maximum fresh and dry shoot weight, whereas the control yielded the lowest weight. Regardless of the soil location,

poultry manure often produced higher fresh and dry shoot weight than granular urea, neem-coated urea, and prilled urea.

3.6 Effect of fertilizer treatments on soil ammonium nitrogen

Treatments' effects on soil nitrogen (ammonium) at 4, 6, and 8 WAP on potted maize during the first and residual harvest on Malete and Shao soil are displayed in Table 8. In comparison to other fertilizer treatments, including control, the impact of applying granular urea at 4 WAP had the highest mean value at Malete potted soil during the first harvest. Neem-coated urea application, however, had the greatest impact on soil ammonium nitrogen at 6 and 8 WAP. The ammonium nitrogen levels from the application of granular urea and neem-coated urea, however, did not differ greatly.

During the first harvest, poultry manure had the most significant impact on soil ammonium nitrogen at 6 and 8 WAP, whereas prilled urea at 4 WAP had the greatest effect at Shao potted soil. The application of neem-coated urea during residual harvest at Malete had the greatest impact on the ammonium nitrogen of potted Malete soil at 4 and 8WAP. At 4 to 8 WAP, the impact of the granular urea and neem-coated amendment was not statistically significant, and there was no significant difference in the ammonium nitrogen levels of the modified soils.

Granular urea had the greatest impact on soil ammonium nitrogen at 4 and 6 WAP in Shao potted soil during residual harvest. At 8 WAP, poultry manure had the greatest impact on soil ammonium nitrogen, while control had the least impact at 4, 6, and 8 WAP.

Table 8
Effect of treatments on Ammonium nitrogen (mg/kg) during first and residual harvest on Malete and Shao soil

Treatment	Malete			Shao		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
	———(mg/kg) ———			——— (mg/kg) ———		
First harvest						
Control	3.1d	19.0c	15.0c	4.3d	5.2c	7.0d
Prilled urea	10.3b	22.0b	24.0b	12.8a	5.8c	7.8d
Neem coated urea	9.4c	27.0a	31.4a	6.4c	8.3b	10c
Granular urea	20.4a	25.0a	29.1a	8.2b	11.6a	13b
Poultry manure	10.7b	21.0b	22.7b	8.6b	11.5a	16a
Residual harvest						
Control	7.3c	8.8c	9.5c	10.1	11.3d	10.0c
Prilled urea	10.4b	11.5b	14.7b	13.7	19.6a	12.6b
Neem coated urea	14.7a	16.6a	20.5a	11.8	16.5b	12.5b
Granular urea	13.6a	17.7a	19.5a	14.7	19.6a	12.7b
Poultry manure	10.4b	10.6b	10.9c	7.6	13.8c	16.5a

Means having the same letter along the columns indicate no significant difference

using Duncan’s Multiple range test at 5% probability level

3.7 Effect of fertilizer treatments on soil nitrate nitrogen

In the first and residual harvests of potted maize on Malete and Shao soil, Table 9 shows the impact of treatments on soil nitrate nitrogen at 4, 6, and 8 WAP.

In contrast to prilled urea, neem-coated urea, and the experiment's control, the study demonstrated that applying granular urea and poultry manure raised the concentration of nitrate nitrogen. When compared to poultry manure, granular urea incorporation generally resulted in higher nitrate nitrogen levels, while some of the increases were not significantly different (Table 9).

When neem-coated urea was applied to potted soil from Malete, NO_3-N at 4 WAP increased significantly (by 80%) in comparison to the control. Granular urea application at 6 and 8 WAP had a considerable nitrate nitrogen effect, but there was no significant difference in the amount of NO_3-N released between granular urea and poultry dung at 6 WAP. At 4, 6, and 8 WAP, the addition of poultry manure to Shao

potted soil greatly increased the release of NO_3-N compared to other amendments. At 4, 6, and 8 WAP, there was no discernible difference between the amount of NO_3-N released from poultry manure and granular urea.

The application of neem-coated urea during residual harvest at Malete had the greatest impact on potted soil nitrate nitrogen at 4 WAP. With the exception of granular urea at 8 WAP, the greatest NO_3-N found in poultry manure at 6 and 8 WAP differed significantly from other modified soil. Applying poultry manure to Shao potted soil during residual harvest raised NO_3-N at 4 WAP. When compared to the control at 4 WAP, a noteworthy 56% increase was noted using poultry manure. Granular urea and prilled urea both exhibited similar effects on NO_3-N at 6 WAI. Poultry manure, however, had the greatest NO_3-N content at 8 WAP, 35% higher than the control soil.

Table 9
Effect of treatments on Nitrate nitrogen (mg/kg) during first and residual harvest on Malete and Shao soil

Treatment	Malete			Shao		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
	———(mg/kg) ———			——— (mg/kg) ———		
First harvest						
Control	6.8d	52.1d	51.2d	5.1c	7.4c	9.2d
Prilled urea	22.6c	62.5b	56.7c	6.5c	9.5c	12.6c
Neem coated urea	34.4a	55.6c	58.8c	11.8b	14.7b	17.7b
Granular urea	28.5b	70.5a	76.5a	14.4a	18.5a	24.7a
Poultry manure	24.7c	70.6a	66.6b	15.5a	19.7a	25.8a
Residual harvest						
Control	11.5d	14.5d	7.5c	8.6d	21.3d	18.7c
Prilled urea	15.7c	19.7c	15.6a	15.6b	34.5a	21.7b
Neem coated urea	25.6a	29.5b	12.8b	11.2c	29.6b	21.7b
Granular urea	23.4a	30.6b	14.6a	16.2b	34.7a	22.6b
Poultry manure	18.4b	36.3a	14.5a	19.5a	24.5c	28.8a

Means having the same letter along the columns indicate no significant difference

using Duncans Multiple range test at 5% probability level

3.8 Combined analysis of variance for NH_4-N and NO_3-N released from potted soils in Shao and Malete during laboratory incubation

In Shao and Malete, combined analysis of variance for NH_4^+-N and NO_3-N released from potted soils during laboratory incubation is shown in Table 10. For both ammonium nitrate and nitrate nitrogen, the mean square resulting from treatment was considerable. For both ammonium nitrate and nitrate nitrogen, mean squares attributed to soil were not significant. Both ammonium nitrate and nitrate nitrogen had large mean squares resulting from treatment and soil interactions.

Table 10
Mean square from combined analysis of variance for the soils in Shao and teaching and research farm during laboratory incubation

————Eight weeks at incubation————			
Source	Df	NH_4-N	NO_3-N
Treatment	4	0.11**	0.37**
Soil	1	0.00ns	0.00ns
Trt*Soil	4	0.13**	0.42**
Residual	20	0.02	0.2
Df: Degree of freedom; *, **: not significant and highly significant at p 0.01 respectively			

3.9 Correlation of nutrients released with time by fertilizers

Table 11 shows the correlations of nutrients released over time by fertilizers incubated in a lab. The coefficient of correlation (r) between NH_4^+-N released at Shao and time was lowest (r = 0.35) in the control and highest (r = 0.89) in Neem coated urea (NCU) throughout the course of eight weeks (sampling at four, six, and eight weeks of incubation). The coefficient of correlation (r) between NH_4^+-N released in Malete was highest in NCU and prilled urea (r = 0.91) and lowest in control (r = 0.65).

Table 11

Correlation of nutrients released with time by fertilizer types under laboratory incubation

	—— NH_4-N g kg^{-1}——	—— NO_3-N g kg^{-1}———	
Treatment	Regression equation r	Regression equation	r
Shao			
Control	y = 0.096x -0.018	0.35y = 0.302x-0.436	0.67
Prilled urea	y = 0.144x-0.128	0.79 y = 0.304x-0.412	0.89
NCU	y = 0.17x-0.226	0.89 y = 0.291x-0.372	0.92
Granular urea	y = 0.221x-0.349	0.83 y = 0.381x-0.611	0.85
Poultry manure	y = 0.168x-0.146	0.81 y = 0.301x-0.263	0.81
Malete			
Control	y = 0.127x-0.135	0.65 y = 0.235x-0.253	0.65
Prilled urea	y = 0.167x-0.201	0.91 y = 0.298x-0.358	0.90
NCU	y = 0.219x-0.305	0.91 y = 0.394x-0.552	0.91
Granular urea	y = 0.164x-0.194	0.87 y = 0.333x-0.429	0.92
Poultry manure	y = 0.145x-0.049	0.69 y = 0.288x-0.146	0.74

* Significant, $p < 0.05$. The regression equations in the table represent the relationship between the calculated value (x) and the predicted value by model (y).

The NO_3-N produced in Shao showed the lowest correlation (r) with time (r = 0.67 in control) and the strongest correlation (r = 0.92) in NCU. Granular urea had the highest coefficient of correlation (r) between NO_3-N released in Malete (r = 0.92), whereas control had the lowest (r = 0.65).

Table 11
Regression equation and Correlation of nutrients released with time by fertilizer types under laboratory incubation

	—— NH_4-N g kg^{-1}——	—— NO_3-N g kg^{-1}———	
Treatment	Regression equation r	Regression equation	r
Shao			
Control	y = 0.096x -0.018	0.35y = 0.302x-0.436	0.67
Prilled urea	y = 0.144x-0.128	0.79 y = 0.304x-0.412	0.89
NCU	y = 0.17x-0.226	0.89 y = 0.291x-0.372	0.92
Granular urea	y = 0.221x-0.349	0.83 y = 0.381x-0.611	0.85
Poultry manure	y = 0.168x-0.146	0.81 y = 0.301x-0.263	0.81
Malete			
Control	y = 0.127x-0.135	0.65 y = 0.235x-0.253	0.65
Prilled urea	y = 0.167x-0.201	0.91 y = 0.298x-0.358	0.90
NCU	y = 0.219x-0.305	0.91 y = 0.394x-0.552	0.91
Granular urea	y = 0.164x-0.194	0.87 y = 0.333x-0.429	0.92
Poultry manure	y = 0.145x-0.049	0.69 y = 0.288x-0.146	0.74

* Significant, $p < 0.05$. The regression equations in the table represent the relationship between the calculated value (x) and the predicted value by model (y).

4 Discussion

4.1 Soil characteristics

The two sites (Shao and Malete) have loamy sand soils that have a neutral pH and are generally low in total nitrogen and phosphorus. Therefore, in order to increase the fertility of the soil, fertilizers or soil amendments were needed. The critical level of 10–16 mg kg-1 was exceeded by the available P of 3.10 and 4.0 mg/kg mg kg-1 (Adeoye and Agboola, 1985). The soil's K status, which was 0.62 and 0.26 cmol/kg, was over the critical level of 0.2 cmol kg-1 (Adeoye, 1986). The critical value of 0.20 to 0.40 cmol/kg-1 was exceeded by exchangeable magnesium values of 1.04 and 0.91 cmol/kg (Adeoye and Agboola, 1985). According to Agboola and Corey (1972), calcium values of 3.16 and 2.83 cmol/kg were greater than the critical level of 2.6 cmol/kg. The low amount of nutrients in the soil indicates that it may respond well to the nutrients that are applied, which is a crucial factor in choosing the experimental soil.

4.2 Characteristic properties of the poultry manure used for the study

Depending on the material often used, such as the length of the breeding season, the features of the poultry house, and the feed content of the birds, the nutrient content of chicken dung might vary. For these reasons, the qualities of the poultry manure collected in relevant literature studies were compared to the characteristics of the poultry manure employed in this investigation. N 2.2–2.5%, P 0.21–1.07%, and K 1.7–3.41 are the value ranges of certain features of any poultry manure found in literature studies. It may be inferred from these ranges of values that all of the poultry manure's values lie within them (Essilfie et al., 2024; Olowoake et al., 2021).

4.3 Soil nitrate and ammonium-nitrogen under amendment

In Shao soil, the effects of urea treatment on Nitrate-N (NO_3-N) at 8 weeks showed a significant difference between the treatments, with the control having the lowest amount of net mineralized Nitrate-N (NO_3-N). Mineralization of immobilized N could be the cause of this (Rummel et al., 2021). The high nitrate released by granular urea demonstrated the strong nitrification rate, while the poor NO_3-N production by neem coated urea at Shao suggested that neem inhibited nitrification (Ali et al., 2020). The emission of NO_3-N throughout the incubation period at Malete indicates that the poultry manure mineralized between weeks 6 and 8. Islam et al., (2021) discovered that soils amended with poultry litter had a mineralization phase after an immobilization phase that lasted up to 30 days.

In Shao and Malete soil, the concentration of NO_3-N rose while that of NH_4-N fell, indicating that a significant portion of the $NH4^+$-N in the soil was converted to NO_3-N and that nitrification is the primary causes of N losses (Abbasi and Adams, 2000; Abbasi et al. 2021). Additionally, the study's findings indicated that the decrease in $NH4^+$-N concentration in Shao and Malete soil, particularly after a two-week incubation period, may be the result of limited Nitrosomonas and Nitrobacter activities caused by nitrification inhibition by applied natural substances. This is in line with other studies that found that nitrobacteria activities were delayed by the application of nitrification inhibitors (Cui et al., 2021; Ayiti and Babalola 2022). The slow release of $NH4^+$-N in Malete soil using neem-coated urea was caused by the neem oil ability to prevent water from penetrating the urea granule. It may also have been caused by the neem oil's ability to inhibit urease activity in the soil (Butnan et al., 2023; Ali et al., 2020). Also, by reducing the rate of nitrification, more nitrogen remains in the ammonium form for a longer period, which is less prone to leaching compared to nitrate.

4.4 Effect of nitrogen sources fertilizers on growth parameters and dry matter yield during first and second planting on Shao and Malete soil

Compared to other fertilizer treatments, including control, poultry manure significantly improved maize plant height, number of leaves, stem girth, fresh and dry shoot weight during the first and second plantings at various phases of maize growth using 120 kgN/ha. According to various studies, using 120

kg N/ha of poultry manure greatly increased maize productivity and growth (.Adekiya et al., 2020; Oad et al., 2004). Akongwubel et al. (2012) who found that when organic manure rates increased over time, there was a significant rise in the accumulation of dry matter in maize. This might be because the organic manure can provide the nutrients needed to encourage faster development, enhance the plants' meristematic and physiological processes, and improve the qualities of the soil. The impact of the different soil types on the performance of every growth and yield parameters identified in this investigation did not differ significantly. The use of the same quality of poultry manure and comparable experimental conditions in both soil types may be the reason for the lack of performance variations in all growth and yield parameters.

A study comparing the effects of granular urea and neem-coated urea as fertilizer treatments showed that the former was more beneficial on maize growth parameters. This outcome is in line with the findings of Olowoake et al. (2022), who found that granular urea, a slow-releasing nitrogenous fertilizer, produced more grain and straw than prilled urea in the pearl millet-wheat cropping sequence. Comparing the pot without fertilizer treatment to other nitrogenous fertilizer treatments, it was found that the maize plant height, stem girth, number of leaves, fresh shoot weight, and dry shoot weight were all lower. This could be because the soil has low levels of nutrients, particularly N and P.

4.5 Soil mineral N dynamics at first and residual harvest

Among the fertilizer treatments, N mineralization and immobilization were demonstrated by the emission of $NH4^{+}$-N and NO_3-N during the first and residual harvest. Sims's (1986) research, which indicated that soils modified with poultry litter had a mineralization phase after an immobilization phase that lasted up to 30 days, is in line with this. The first and residual harvests also showed a notable NO_3-N response to granular urea and poultry manure, which was a result of the granular urea's oxidation to NO_3-N and the poultry manure's NH_4^{+}-N content (Uddin et al., 2021). N from poultry dung did not mineralize at the initial harvest until four weeks later.

Similarly, poultry manure did not significantly improve maize growth parameters, indicating that N mineralization from poultry manure during the first harvest was too slow. This could be attributed to their incapacity to supply N in a bioavailable form in a quantity and time that corresponds with crop demand (Eghball et al. 2025))

4.6 Correlation studies

The ammonification of organic N may have contributed to the increase in NH4+-N content in Shao and Malete soil, which had the highest $NH4^{+}$-N values in the correlation of nutrients released with time. In investigation of the behavior of ammonium in soil, Ferraz-Almeida (2024) found that the element was present in the subsurface layers, indicating that it moved in tropical soils.

In comparison to mineral fertilizers, organic fertilizers generally have a larger residual effect on the soil (Singh et al., 2020). This trend can be explained by the organic molecules' gradual mineralization, which

prolongs the time that the nutrients are available. Therefore, in contrast to mineral fertilizers, these nutrients are less susceptible to chemical reactions in the soil.

4.7 Ecological impact of fertilizer types

The differences among poultry manure, prilled urea, granular urea and neem coated urea reflect fundamental contrasts between organic slow mineralization and rapid mineral N supplied by urea, plus the modifying effects of coatings/inhibitors on microbial transformations. From an environmental standpoint, unmodified urea forms present the highest immediate risk of NH_3 volatilization and, if nitrified when not taken up, subsequent NO_3^- leaching and N_2O emissions occurred (Zhang et al., 2022). Neem-coated urea and other inhibitor strategies consistently reduce some of these losses and often improve apparent nitrogen use efficiency (NUE) in maize, this is supported by Chakrabarti et al., (2024) who reported that the use of neem oil coated urea reduced the N_2O–N emission by 10.3%. In contrast, manure can produce NO_3^- later in the season as mineralization proceeds; if that timing does not match crop demand it can also contribute to leaching. These seasonal patterns are consistent with the report of Cook, (2025) on manure N mineralization dynamics.

5 Conclusions

N mineralization in the fertilizer treatments was demonstrated by the incubation investigation. N mineralization in Malete soil revealed that poultry manure and Neem-coated urea produced the highest NO_3-N and NH_4^+-N mineralized respectively with nitrification at 64% over ammonification, indicating prevention of N loss through volatilization. In Shao soil, approximately 98.5 and 98.7% of the total NO_3-N and $NH4^+$-N applied as granular urea were mineralized within 56 days of incubation. Granular urea and poultry manure applied at a rate of 120 kg N/ha were found to improve maize growth parameters and dry matter yield in the two potted soils (Malete and Shao) during both the first and second harvests.

In summary, poultry manure has the potential to be a labile source of nutrients that promotes crop growth, dry matter production, and N release. Poultry manure applied at a rate of 120 kgN/ha can also more effectively augment residual soil fertility in maize (Zea mays L) production.

For farmers, these findings suggest that use poultry manure can maximize maize yield, enhance soil health, and reduce fertilizer costs over time. For policy makers, the study underscores the need to promote the adoption of organic inputs (like composted poultry manure) through extension services, input subsidies, and environmental regulations. Such strategies will not only improve nitrogen use efficiency and crop productivity but also contribute to sustainable soil management, reduced greenhouse gas emissions, and long-term food security.

Declarations

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Figures

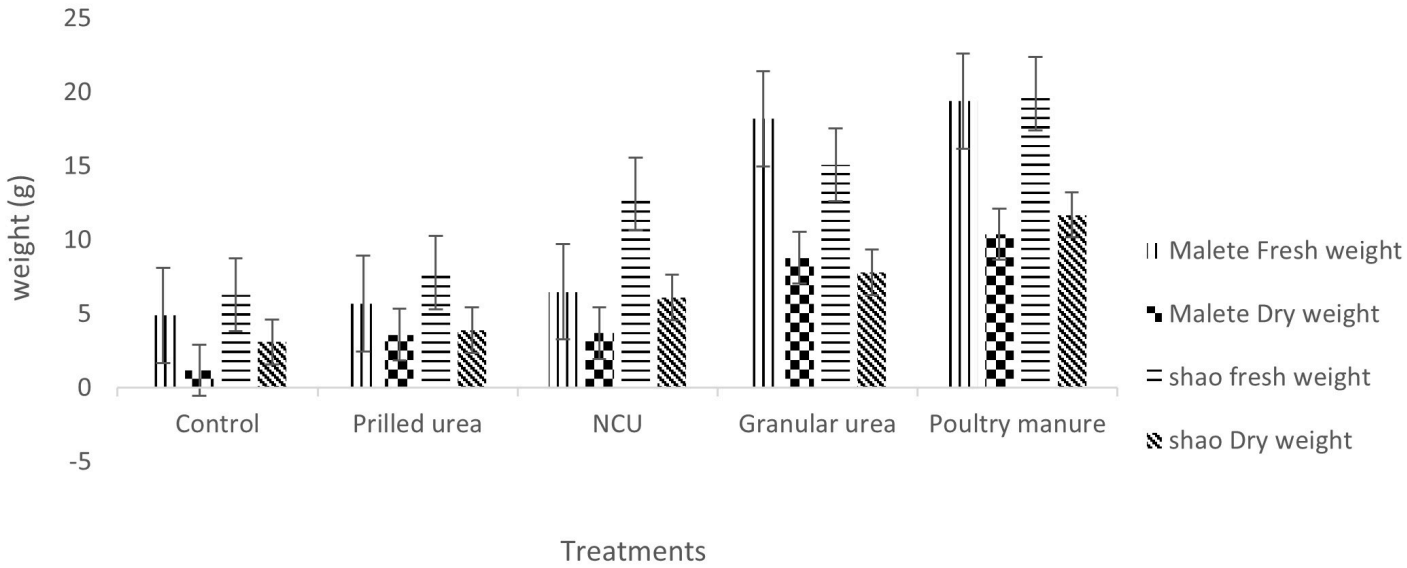


Figure 1a. The effects of poultry manure, urea and neem coated urea on maize fresh and dry weight during first planting on Malete and Shao soil

Figure 1

See image above for figure legend.

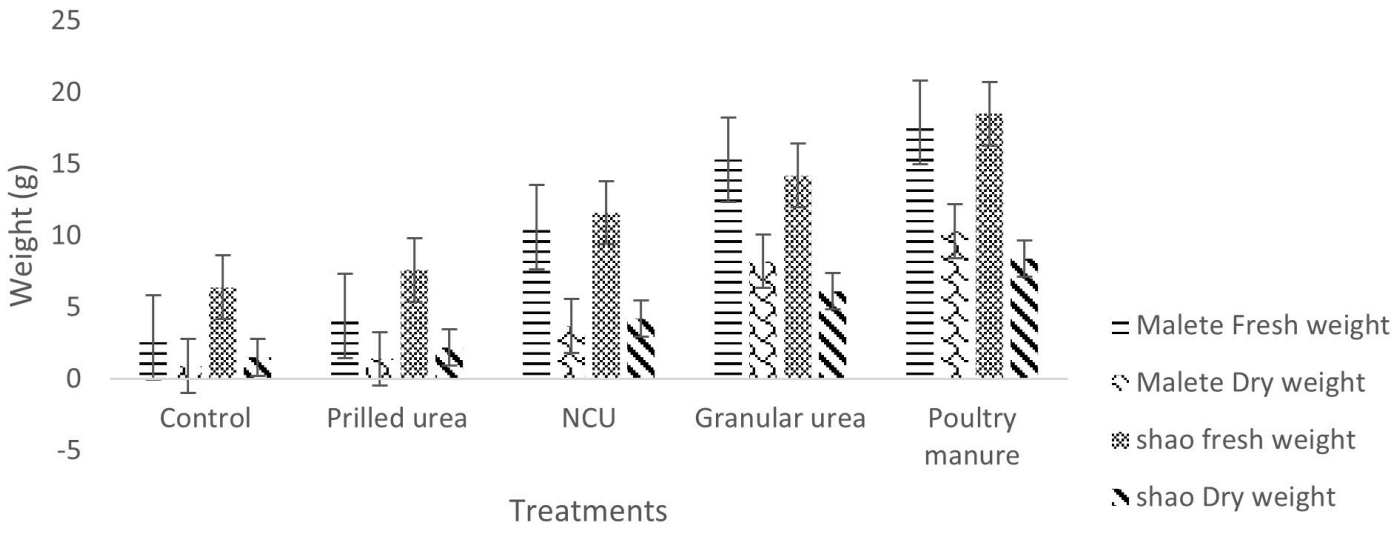


Figure 1b. The effects of poultry manure, urea and neem coated urea on maize fresh and dry weight during second planting on Malete and Shao soil

Figure 2

See image above for figure legend.

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